CHAPTER 5

ELECTRIC DISTRIBUTION LINES

5-1. Selection.

Criteria for electric distribution lines will be based on the requirements of agency criteria. Distribution lines will be sized to meet current demand load, future loads, and line-loss factors.

a. Aerial line requirements. Aerial lines will be used in all areas, except in the following instances:

(1) Where aerial lines would constitute hazards such as near flight lines (where poles must be outside of the glide path) or near munitions buildings (where poles can be no closer than the length of the lines between the poles which support the lines unless effective means is provided to assure that energized lines cannot, on breaking, come in contact with the facility or its appurtenances).

(2) Where aerial lines would obstruct operations (e.g., interfere with crane-type, materials-handling equipment).

(3) Where aerial lines would interfere with high-frequency communication or electronic equipment. Aerial lines will not be within 250 feet of Communications-Electronic-Meterological (CEM) Operation Buildings, not within 1,500 feet of receiving antennas, and not within 1,000 feet of other antennas.

(4) Where aerial installations would conflict with current policy for Family Housing Areas.

(5) Where areas have such high load densities that underground electric lines are economical. For Air Force projects, underground installation must be approved by the HOST COMMAND.

(6) Where aerial lines would be incompatible with the environment or architectural concept. For Air Force projects, underground installation must be approved by the HOST COMMAND.

b. Underground line requirements. Underground distribution lines will be provided for the exceptions listed above, for minor extensions to existing areas served by underground distribution lines, and for medium-voltage or large low-voltage electric services to buildings. When tying into an existing asbestos composite duct bank, proper environmental protocol will be followed.

5-2. Types of Underground lines.

There are two methods of installing underground lines, In the first method, underground raceway systems (ducts) are installed below grade and then cable is pulled through them. Ducts may or may not be provided with concrete encasement. The second method consists of underground cable systems installed directly in the ground. Cables may be the direct-burial type cable assemblies in coilable plastic duct, or cable assemblies in metallic armor (in direct-burial rated sheath). In this manual, the word duct will be used rather than conduit.

a. Requirements for medium-voltage lines. Where underground systems are provided, the following standards will be followed:

(1) In industrial and densely populated areas, cables will be installed in underground duct lines with manholes. Ducts will be concrete encased.

(2) In lightly populated areas, cable may be placed in non-concrete-encased duct or buried directly.

(3) The use of direct-burial cable will be limited to long untapped runs in lightly populated areas where the reliability requirements are low; or the facilities served by the cables have a short-term life; or for other reasons which would justify the use of the more economical direct-burial installations.

*b. Secondary distribution lines and service con*ductors. Where underground systems are provided, the following guidelines will be observed:

(1) In industrial and densely populated areas, cables be installed in underground duct lines (with manholes, handholes, or pullboxes as applicable). Ducts will be concrete encased.

(2) In lightly populated areas, cable in non-concrete-encased duct or direct cable may be used.

(3) Low-voltage direct-burial cable will be restricted to applications where the load to be served is not anticipated to be increased; the underground cable can be replaced easily upon failure; and the cable system is not subject to disturbance or physical damage. The designer will coordinate burial requirements with the using or maintaining organization.

5-3. Types of Aerial lines.

Bare conductors will be used for medium-voltage circuits and insulated conductors will be used for low-voltage circuits.

a. Open wire medium-voltage construction. Bare wires will be installed on pole lines using either armless or crossarm construction. Since armless construction is more economical and presents a more pleasing appearance, it will be provided for new lines, except where prohibited by technical considerations, such as a line with many taps, crossings, or overhead-to-underground transitions. Also, armless construction requires bucket trucks for maintenance due to loss of climbing space.

b. Insulated cable lines. Aerial insulated cables will be of the factory-assembled, messenger-supported type. The use of self-supported insulated cable or of messenger-supported insulated cable with insulated spacers will not be used.

(1) *Medium-voltage lines.* Such construction is advisable where it is necessary to avoid exposure to open wire hazards, for example, high reliability service in heavy storm areas. Cable will be of the factory-assembled, messenger-supported type.

(2) *Low-voltage lines.* Low-voltage lines will be of the neutral-supported secondary and service drop type which uses a bare messenger as a neutral conductor and as a support for insulated phase conductors. Weatherproof conductors (line wires), which are supported on secondary racks, are less attractive and more expensive to install then neutral-supported cable. Use of secondary-rack construction will be limited to minor extensions of existing systems.

5-4. Voltage Drop.

Voltage drop on the distribution system will comply with the minimum voltage requirements of ANSI C84.1. Voltage drop on the low-voltage distribution system will comply with the recommendations of the NEC. Figure 5-1 shows typical distribution of voltage drops through the supply system. Designers will consider all the system voltage drops in order to ensure that voltage levels are in accordance with ANSI C84.1 and the NEC.

a. Voltage drops. An example of an aerial line voltage drop calculation is given on figure 5-2. This example uses the approximate formula method which ignores angles and which is sufficiently accurate for all but abnormal conditions, such as where system power factors are extremely low. Proximity effects, sheath currents, and geometric construction may need to be taken into account in calculations of impedance for underground circuits. Various tables and voltage drop curves are available from manufacturers for underground circuits. For aerial circuits, impedance may be determined using values of resistance and reactance.

b. Resistance. For conductors of 500 kcmil and less at 60 Hz frequencies, the skin-effects of alternating current are negligible and direct-current resistance values can be used.

c. Reactance. Normal practice is to separate inductive reactance into two components. Xa is the reactance which results from flux within a radius of one foot of the conductor plus the internal reactance of the conductor. Xd is the reactance which results from flux between the radius of one foot and the equivalent conductor spacing based on a mean distance (D). The two values of reactance can be found in conductor tables and added together for the total alternating-current reactance.

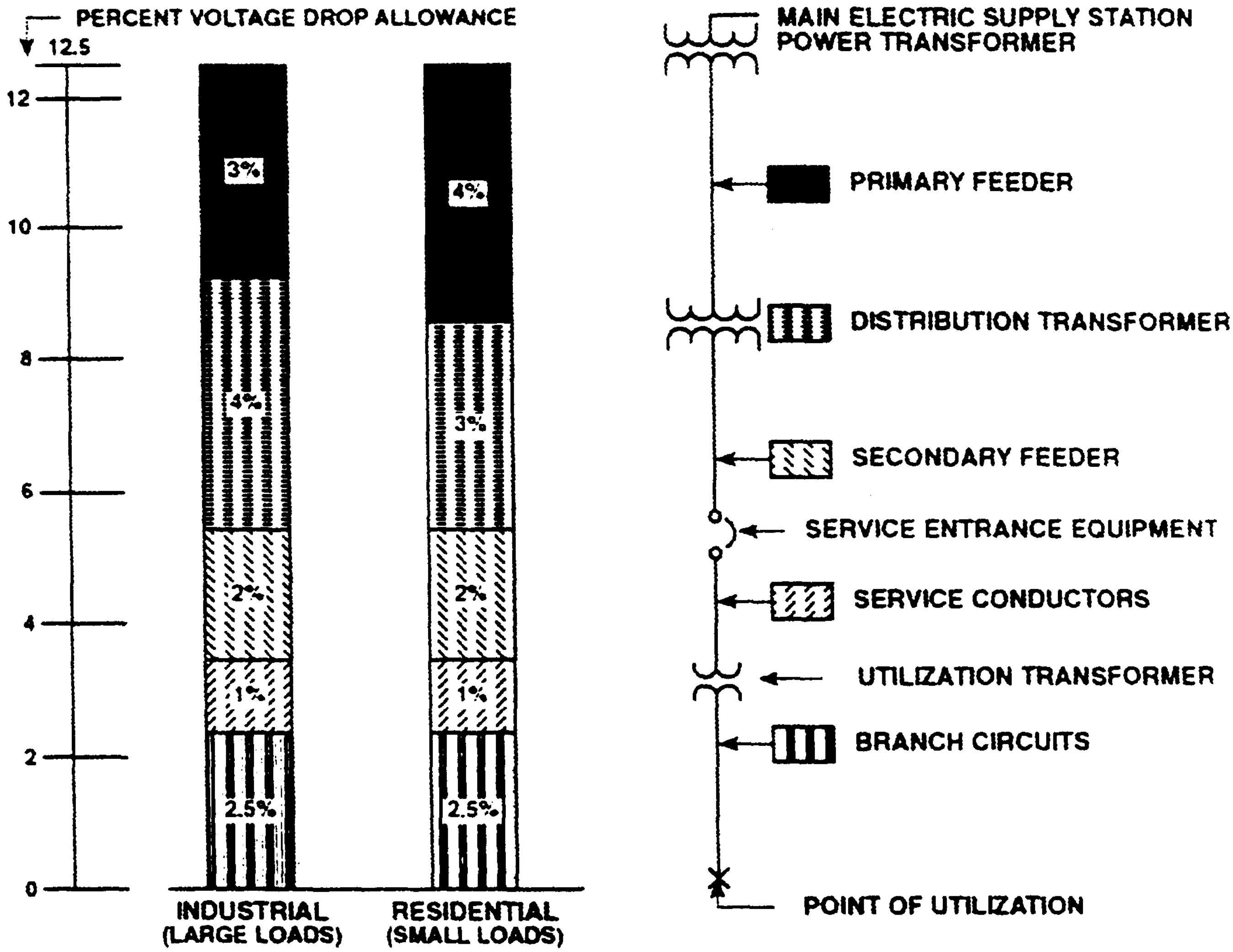
5-5. Power Factor Correction.

System power factor is influenced mainly by the characteristics and mechanical loads of the motors supplied. Such characteristics vary widely and therefore the kVAR capacity cannot be correctly estimated at the time of the distribution system design, but only after firm data is available. One year of operating history is needed before the amount of fixed and switched capacitance can be selected to best meet actual operating conditions. Large motors are often provided with integral capacitors.

a. Capacitor justification. Justification for application of line and station shunt capacitors requires a life-cycle cost analysis using the methodology in 10 CFR 436. Capacitors are justified when the savings to investment ratio of the installation is greater than one. An example of computing the average energy savings per year is shown on figure 5-3. Where a serving utility does not have a power factor clause, only line losses will apply.

b. Capacitor equipment. Capacitors for overhead distribution systems can be pole-mounted in banks of 300 to 1,800 kVAR for most medium-voltage systems up to 34.5 kV phase-to-phase. Pad-mounted capacitor equipment is available in the same range of sizes and voltage ratings for underground systems. Power capacitor equipment will have grounded wye connections so switch tanks and frames will be at ground potential for greater personnel safety. Grounded capacitors can bypass some line surges to ground, provide a low impedance path for harmonics, and group fusing need not be so precise. For maximum efficiencies, capacitor equipment will be located as close to the load controlled as is feasible. Surge arresters will be specified to limit the magnitude of voltage surges caused by capacitor switching. Applications of surge arresters will be in accordance with the IEEE C62 series of standards.

c. Capacitor control. Switched capacitors will be provided only when differences between full-load and light-load power factors warrant such control. The load and power factor profile of the system will determine the economics of switched control, and whether there is a necessity for more than one switching step. Time clock control is the least costly type of control, but can only be used where power factor and demand vary on a firm time



NORMAL ALLOCATION OF VOLTAGE DROP

Figure 5-1. Normal Allocation of Voltage Drop.

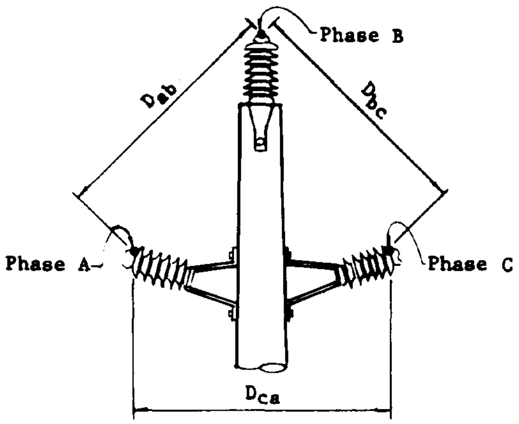
basis. Voltage control is used where objectionable voltage changes occur with varying voltages. Current control is used when loads change, but voltage is well regulated or load power factor remains substantially constant. Current control is effective also when power factor varies in a predictable manner with the load. Kilovar control is used when load voltage is regulated, but power factor varies in an unpredictable manner to corresponding load variations. More sophisticated current and voltage control than that covered by IEEE Std 18 can be provided, and manufacturers should be consulted for application and specification information.

5-6. Medium-Voltage Circuits.

a. Number. The number of medium-voltage circuits will be determined on the basis that each circuit must be capable of serving the load over the required distance without exceeding the allowable voltage drop. The number of circuits and conductor sizes will be determined by an economic evaluation of the possible configurations including construction requirements (span lengths, pole heights, pole classes) for conductor capacities at the primary distribution voltage and higher voltages.

(1) *Quick check values.* Table 5-1 has been prepared to allow a quick check of the capacities of three-phase medium-voltage circuits at 0.90 power factor by giving the approximate kilovolt-ampere-mile loading for a three percent voltage drop. For voltages not given, the use of a factor of the square of the ratio of the desired voltage divided by the known voltage times the megavolt-ampere-

IMPEDANCE FACTORS



$Z = R + j\,(X_a + X_d)$ ....(1)

Where:

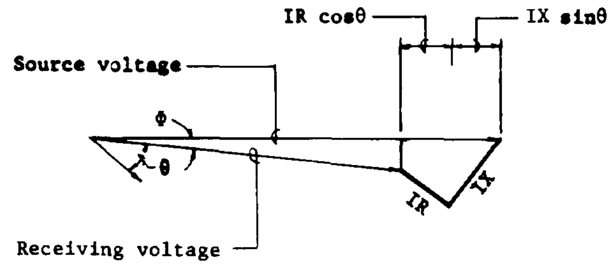
R = 60 Hz resistance

X_a = 60 Hz inductive reactance at 1-foot spacing

X_d = 60 Hz inductive reactance for additional spacing D

$D = [(D_{ab})(D_{bc})(D_{ca})]^{1/3}$ .....(2)

APPROXIMATE VOLTAGE DROP FORMULAS



Line-to-line voltage drop

$= 1.732\, I\, (R \cos\theta + X \sin\theta)$ ....(3)

Where: I = Line current in amperes

θ = Phase angle between voltage and current or cosθ = power factor

R = Resistance of line in ohms, one conductor

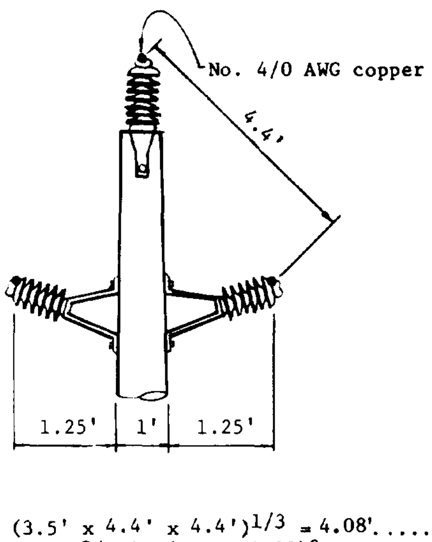
X = Reactance of line in ohms, one conductor

Formula (3) can be converted as follows to calculate percent voltage drop:

$$\%\ \text{voltage drop} = \frac{\text{kVA}\,[R\cos\theta + (X_a + X_d)\sin\theta]}{10\,(\text{kV})^2} \quad \text{...(4)}$$

Where: kVA is three-phase kVA and kV is line-to-line kilovolts. For single-phase circuits the percent drop is twice this value, and kVA is single-phase kVA.

EXAMPLE



Given:

cosθ = 0.90	sinθ = 0.436
kVA = 15,000	kV = 13.8

Find voltage drop for one mile of line

Percent voltage drop =

$$15{,}000\left[\frac{(0.278)(0.9) + (0.674)(0.436)}{10(13.8)^2}\right]$$

= 4.28% voltage drop ....(4)

$(3.5' \times 4.4' \times 4.4')^{1/3} = 4.08'$......(2)

0.278 Ω/mile (Table 4-29)[a]

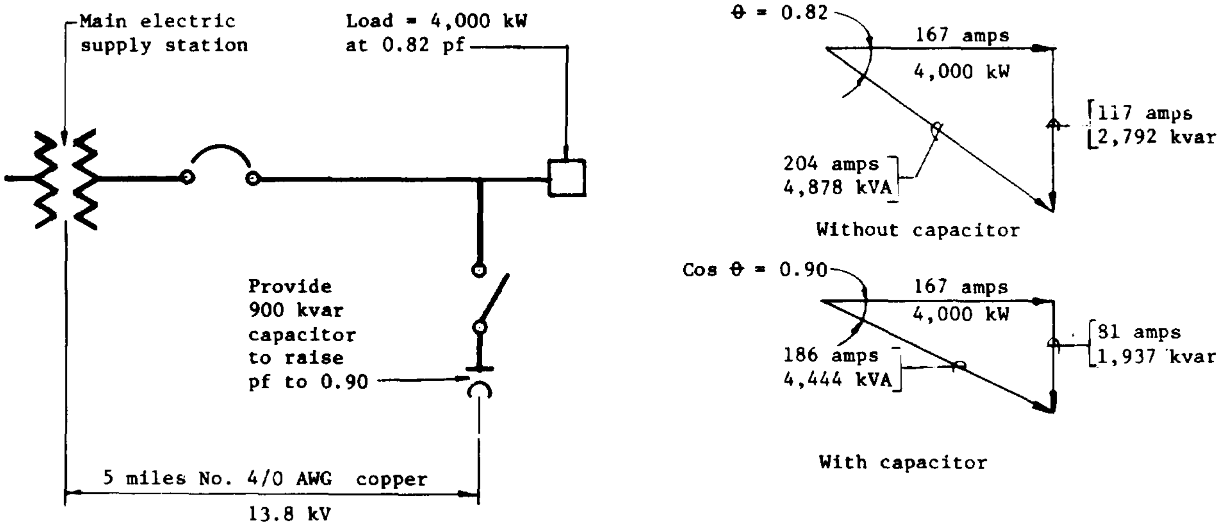
0.503 Ω/mile (Table 4-29)[a]

0.171 Ω/mile (Table 4-34)[a]

0.278 + j0.674 Ω/mile...............(1)

[a]Tables are from Standard Handbook for Electrical Engineers (Eleventh Edition).

Figure 5-2. An Example of Voltage Drop Calculation.



SINLE LINE DIAGRAM

VECTOR DIAGRAMS

ASSUMED UTILITY RATES

Energy charge
- $0.035 per kWh

Power factor clause credit
= 0.001 times value in percent that power factor (pf) is raised above a stipulated amount.

CALCULATIONS

Losses - I^2R
= $[(204^2 - 186^2)$ amperes] x 5 miles x 3 conductors x 0.278 ohms per mile
= 29.27 kw

Line loss savings = 29.27 kW x 0.6 load factor x 4,000 hours x $0.035
= $2459 a year

Power factor savings (increase 82 percent to 90 percent)
= 4,000 kW x 0.6 load factor x 4,000 hours x $0.035 x [0.001 x 8]
= $2.690 a year

Total Savings = $2459 + $2,690 = $5149 a Year

us Army Corps of Engineers

Figure 5-3. Average Energy Savings Example.

miles will provide a sufficiently accurate determination. For instance, taking the value for aerial No. 4/0 AWG copper at 25 kV or 29.2 megavolt-ampere-miles and multiplying by $(35/25)^2$ gives a value of 57.2 megavolt-ampere-miles which is almost the value given in table 5-1. For underground circuits, where proximity effects apply, a greater variation will be encountered, but estimated demand loads are probably within the same accuracy range.

(2) *New feeders.* For new installations, with estimated demands based on requirements covered in chapter 2 and estimated feeder lengths based on the site plan, a determination of circuit requirements can be made. Feeders will be large enough to allow a growth factor of 25 percent of the design maximum demand.

(3) *Existing feeders.* Circuit capability will be determined by measuring loads over a suitable period of time. Where such information is unavailable, knowledge of the station maximum demand and overall transformer capacity can permit determining an installation's demand factor on the basis of overall connected transformer capacity. Circuit capability can be roughly evaluated by totaling the transformers connected to the feeder and applying this factor; however, this method is too inaccurate as a basis for justifying new feeders or adding large loads.

b. Automatic circuit reclosers. Chapter 4 covers provision of reclosing relays on outgoing feeder circuit breakers at a main electric supply station. Where a reclosing relay on a station circuit breaker does not provide a protective zone which

Table 5-1. Three-Phase Medium-Voltage Circuit Loading Check Values.

Type of line	Material	Wire size AWC or kcmil	Maximum amperes	4.16kV	13.8kV	25kV	35kV
				Megavolt-ampere-mile[b] (Maximum megawatt load)			
Aerial lines[c]	Copper	4/0	480	0.8(3.1)	8.8(10.3)	29.2(18.7)	57.3(26.2)
		2/0	360	0.6(2.3)	6.2(7.7)	22.4(14.0)	44.1(19.6)
		1/0	310	0-5(2.0)	5.9(6.7)	19.5(12.1)	38.1(16.9)
		1	270	0.5(l.7)	5.1(5.8)	16.5(10.5)	32.3(14.7)
		2	230	0.4(1.5)	4.3(4.9)	14.1(8.8)	27.6(12.5)
		4	180	0.3(1.2)	3.0(3.8)	9.8(7.0)	19.2(9.8)
		6	130	0.2(0.8)	2.0(2.8)	6.7(5.1)	13.1(7.1)
	ACSR	336.4	530	0.8(3.4)	9.3(11.4)	30.4(20.7)	59.8(28.9)
		4/0	340	0.5(2.2)	5.9(7.3)	19.4(13.3)	38.0(18.5)
		3/0	300	0.5(1.9)	5.1(6.5)	16.7(11.7)	32.7(16.7)
		2/0	270	0.5(1.8)	4.4(5.8)	14.4(10.5)	28.3(14.7)
		1/0	230	0.3(1.5)	3.7(4.9)	12.2(9.0)	23.9(12.5)
		2	200	0.2(l.2)	2.7(3.9)	8.9(7.0)	17.5(9.8)
Underground lines[d]	Copper	500	465		26.0(10.0)	82.7(18.1)	
		2/0	230		9.9(4.9)	32.4(9.0)	
	Aluminum	350	305		14.5(6.6)	47.2(10.8)	
		4/0	230		9.8(4.9)	31.8(9.0)	
		1/O	155		5.4(3.3)	17.5(6.0)	

[a] For balanced loads.
[b] For loads having a 90 percent power factor thin value represents a 3 percent voltage drop. The values given parenthesis represent the megawatt capacity of the wire and values were computed using the method shown on figure 5-1.
[c] Baaed on values from Standard Handbook for Electrical Engineers (Eleventh Edition) for 60 Hz circuits approximately 75 percent loaded and operating at a temperature of 50° C and an equivalent spacing of 5 feet.
[d] For conductors operating at 40° C.

covers an entire feeder because of circuit length and impedance, automatic circuit reclosers or reclosing circuit breakers may be necessary remote from the station. This application of automatic circuit reclosers will be provided only to protect the aerial portions of the feeder, and only when reclosing is also provided on that feeder at the main electric supply station.

c. Connections to transformers. Normal transformer circuit design will eliminate most circuit elements which produce the destructive voltages which can arise from ferroresonance.

(1) *Overvoltage.* Ferroresonant overvoltages occur when the ratio of the distributed line-to-ground capacitive reactance (Xc) in series with the transformer magnetizing (no-load) inductive reactance (Xm) is nearly equal and the effective resistance in the circuit is minimal (almost no load connected to the transformer). At such times the circuit may be near resonance resulting in a total circuit impedance close to zero. Under these conditions, a high current will flow and cause correspondingly high voltages.

(2) *Overvoltage prevention.* Destructive overvoltages do not occur when group-operated switching is provided. Pole-mounted transformers are switched so close to transformer terminals that there is not sufficient line capacitance for resonance. Clearing of one fuse in a line should not be a problem, because the transformer is loaded at that time. Very rarely are aerial lines long enough to provide enough capacitance to cause ferroresonante.

(3) *Occurrence.* Ferroresonance may occur on long underground circuits which are single-pole switched. Since the occurrence of ferroresonance cannot be reliably predicted, group-operated switches are required for, and should be integral to, ground-mounted transformers.

d. Transition points. Transition points between aerial and underground sections (riser poles) will be provided with primary fuse cutouts and surge arresters for protection of the underground cables and cable-supplied equipment. When the underground service supplies two or more transformers, some of which may be remotely located, fuse cutouts will be of the loadbreak type. When the underground feeder supplies only one transformer installation in the immediate vicinity of the riser pole, nonloadbreak fused cutouts may be acceptable. Where the capacity of the line is more than the maximum ampere rating of fuse cutouts, power fuse units will be installed. Installation of lines having an ampere rating above that of power fuses will be avoided, since more expensive protection devices such as those covered in chapter 4, will be necessary. Group-operated loadbreak switches used for sectionalizing aerial-to-underground connections can be either integrally fused or nonfused devices. Overcurrent protection is necessary to protect underground systems. Group-operated loadbreak switches at transition poles are not justifiable solely on the basis of preventing possible ferroresonance, since such switches at ground-mounted transformers will eliminate most causes of transform ferroresonance.

5-7. Pad Mounted Sectionalizing Equipment.

a. Pad-mounted, metal-enclosed switchgear. Pad-mounted, metal-enclosed switchgear (air-, oil-, gas-, or vacuum-insulated) may be utilized to provide group-operated, load-break switch operation, sectionalizing points for large underground distribution systems, and over-current protection (fuses) for lateral feeders from a main feeder. Additionally, they may be employed to provide group-operated, load-break switch operation for large three-phase loads requiring interruption of all phases simultaneously. Switchgear is also available to provide manual switching between alternate primary sources. Application of switchgear will be based on operational needs, protective devices coordination requirements, size of the primary system and loads, and cost comparisons among alternatives.

b. Pad-mounted sectionalizing terminals. These devices are dead-front, cable-terminating enclosures which employ separable, load-break connectors and load-break, feed-through bushings. They do not provide over-current protection. They provide a means to splice cables above ground and provide lateral feeder taps from a main feeder, while maintaining the ability to sectionalize the underground cables at that point for operation and maintenance. These devices will not be substituted for pad-mounted, metal-enclosed switchgear and should be used only where isolation of lateral feeds is necessary for operation or maintenance and the application does not require a switchgear. They can be used for opening a de-energized circuit during maintenance for fault isolation at a much lower cost than a fused or non-fused disconnect switch. They can also be used to open a de-energized radial feeder for maintenance, again at less cost than a disconnect switch. If provided in a project design, the contract specifications shall include provision of standoff bushings for phase isolation ("parking") of each conductor, and instruction signs on the enclosure which state that the connectors are not to be disconnected/connetted while energized.

5-8. Joint Electrical/Communication lines for Air Force Installations.

a. Electrical. Where overhead construction is required, electrical distribution shall be located along street or roads to avoid the use of separate poles for street lights.

b. Poles, duckbanks, and manholes:

(1) For economy, telephone lines and television cables shall be carried on the same poles or in the same ductbank as electrical power lines.

(2) Joint use of manholes is permitted if the power cables and communications cables are separated from each other by a masonry wall and a separate manhole cover is installed in each section.

c. Additional factors. Underground construction for either electrical distribution or communications systems shall meet the provisions of this manual and technical requirements such as airfield clearance, proximity to radio and radar installations, and security control of closed circuits, unless specifically authorized by a waiver of these criteria.

d. Overhead cable limits. No more than two telephone cables shall normally be installed per pole. Quantity of twisted pairs and conductor sizes (AWG) for cables exceeding diameter and weight limitations begin with:

5 lb/ft *Quantity-AWG*	*2-inch diameter* *Quantity-AWG*
303-19	303-19
606-22	508-22
909-24	909-24

e. Routing of telephone cable. Telephone cables shall not be installed on poles until arrangements have been made for adequate guying.